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Effects of pre-harvest supplemental chlorate on beef carcass and meat quality

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Abstract

Effects of feeding sodium chlorate on carcass quality, tenderness and color stability were evaluated. Heifers ($n = 64$) were fed chlorate at either 0.01% or 0.05% of body weight (BW) in the last feeding or 0.01% for the last 5 d before harvest, while control cattle received no chlorate. During the 12 h period between feed withdrawal and transport to the harvest facility, the cattle were provided water containing either no sodium chlorate or sodium chlorate (approximately 30 mM). Feed treatments at 0.01% of BW produced higher marbling scores than feeding 0.01% of BW for 5 d. However, neither of these treatments produced marbling scores that were different from non-treated controls. Water supplementation increased tenderness in cattle fed 0.01% of BW for 5 d, but decreased tenderness in cattle fed 0.05% of BW at the last feeding. Although tenderness differences existed, it is not clear whether or not they were caused by the feed or water treatments or by pre-existing variation in the cattle. Neither feed nor water supplementation affected color stability. These data suggest that chlorate preparations could be used to reduce pathogens without adversely impacting meat quality or display life. However, further research is needed to further substantiate these findings.
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1. Introduction

Food safety continues to be a primary concern for the beef industry. Controlling food borne pathogens on beef carcasses, cuts and trimmings continues to be the focus of considerable research. Consequently, interventions that can be used to reduce the incidence of pathogenic bacteria on carcasses have been extensively evaluated. Evidence suggests that reducing the incidence of pathogens in fecal material and on hides of animals entering the processing facility will reduce the numbers of these organisms on carcasses (Bacon et al., 2000; Elder et al., 2000).

Reducing the concentrations of pathogens in the gastrointestinal tract, before the animals are transported to the harvest facility would likely reduce the numbers of these organisms on the hide (Brashears, Galyean, Loneragan, Mann, & Killinger-Mann, 2003). One pre-harvest intervention that has been investigated is supplementing cattle with sodium chlorate during the last days before slaughter to reduce pathogenic bacteria while not affecting the natural flora of the gastrointestinal tract (Anderson et al., 2000a; Anderson, Callaway et al., 2000b).

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Chlorate ion is toxic at high concentrations, with a lethal dose for most animals reported to be approximately 1500–5500 mg per kg BW, although the toxicity of chlorates appears to be greater for cattle, with a lethal dose of approximately 1000 mg sodium chlorate per kg BW (Frank, 1948; Radeleff, 1970). Considering, however, that precedence exists for the use of chlorate salts in animal and human medicine and that the use of chlorate in toothpastes at concentrations of up to 5% has been approved by the European Union (Cosmetic Ingredient Review Panel, 1985), the intended use of the experimental chlorate preparations as immediate pre-harvest food safety supplements need not necessarily be precluded provided that toxicity is not encountered. Evidence with rats indicates that chlorate and chlorite do not accumulate in biological systems but are rather reduced to chloride (Abdel-Rahman et al., 1985; National Research Council, 1987). Sodium chlorate is not harmful to animals at the levels needed to reduce the numbers of pathogenic organisms (Cosmetic Ingredient Review Panel, 1985). Therefore, it is a potential candidate for use as a microbial intervention.

The use of "grade and yield" marketing programs is common in the beef industry. Therefore, the price received for carcasses is dependent on carcass grades. Consequently, the adoption of a pre-harvest microbial intervention by the cattle feeding industry is dependent on the ability of the intervention to work effectively without deleterious effects on carcass quality and marketability. The effectiveness of these treatments on the levels of pathogens in the fecal material and on the hides of these animals has been previously discussed by Anderson et al. (2002). Because chlorate has been reported to reduce pathogens in fecal material, data are needed to elucidate the effects of chlorate supplementation on carcass and meat quality attributes. Therefore, the objective of the present study was to evaluate consequences of supplementing cattle with various levels of chlorate in the feed and water on carcass and meat quality.

2. Materials and methods

2.1. Animal selection and chlorate supplementation treatments

Finished heifers ($n = 64$) of Mexican origin were selected for uniformity of live weight from a commercial cattle feeding operation in the Texas panhandle and transported to the USDA/ARS Southern Plains Agricultural Research Center. The cattle were acclimated for seven days before the study commenced. The diet during the acclimation period and experiment was similar in energy content to the diet fed at the feed yard (Table 1).

The heifers were randomly assigned to one of four slaughter groups, which were subjected to treatments two weeks apart. Within slaughter groups, heifers were randomly assigned to feed and water treatments (8 possible combinations). Two heifers were assigned to each feed and water treatment combination in each group. Cattle were fed an experimental chlorate product (EKA Chemicals, Inc., Marietta, GA) at 0%, 0.01% or 0.05% of body weight during the last feeding before harvest. A fourth treatment, 0.01% of body weight, was fed for the last 5 d on feed. The experimental chlorate product provided in the feed was a proprietary preparation that contained 40% active chlorate ion and 4% active nitrate ion (as an inducer of respiratory nitrate reductase activity) by weight and was mixed in the feed immediately before each feeding. Half of the animals were given ad libitum access to water containing no chlorate during the 12 h following feed withdrawal, but before the animals were transported to the processing facility. The remaining animals were given ad libitum access to a water solution containing approximately 30 mM $NaClO_3$ during the same time period. Amounts of feed and water consumed were measured and have been reported previously (Anderson et al., 2002).

Table 1
Composition of the diet fed to heifers during the study prior to the addition of sodium chlorate

Ingredient	%
Steam rolled corn	79.50
Cotton seed meal	7.39
Vitamin premix	0.05
Trace mineral premix	0.05
Urea	0.98
Cotton seed hulls	6.49
Soy oil	3.61
Limestone	1.43
Salt	0.50

2.2. Carcass evaluation and sample collection

The heifers were transported, approximately 150 km to a commercial processing facility where they were harvested using standard procedures. After chilling at 2 °C for 24 h, the left side was ribbed between the 12 and 13th rib and allowed to bloom for approximately 30 min. USDA yield and quality grade factors were determined by trained Texas A&M University personnel. USDA yield grade could not be calculated for carcasses from the first slaughter group because the kidney fat, a factor in determining yield grade, had been removed on the harvest floor. For the remaining slaughter groups, the kidney fat was not removed; and therefore, the percentage kidney, pelvic and heart fat was estimated in these carcasses.

The beef loin, strip loin, boneless (IMPS #180; NAMP, 1997; USDA, 1996) was removed from the left side of each carcass, packed in ice, and transported to the Texas A&M University Rosenthal Meat Science and

Technology center in insulated coolers. Upon arrival, the strip loins were vacuum packaged and aged for 14 d. Following aging, two 2.54-cm thick steaks were removed from the cranial aspect of the *M. longissimus lumborum*. The first steak was vacuum packaged and frozen (−10 °C) for Warner–Bratzler shear force determination. The second steak was used for simulated retail display.

2.3. Warner–Bratzler shear force determination

Frozen steaks were thawed overnight in a 4 ± 2 °C cooler before cooking. Steaks were cooked on a Farberware Open Hearth Electric Broiler (Farberware, Inc., Corning, NY). The internal temperature of each steak was monitored using a type K thermocouple attached to a hand-held microprocessor digital thermometer (model HH-21, Omega Engineering, Inc., Stamford, CT). Steaks were turned when the internal temperature reached 35 °C and were removed from the grill at 71 °C according to AMSA (1995). The steaks were then covered with Saran® wrap to prevent dehydration and chilled overnight in a 4 ± 2 °C cooler.

Six 1.27-cm diameter cores were removed parallel to the muscle fiber orientation. Cores were sheared with a Universal testing machine (model SSTM-500, United Calibration Corp., Huntington Beach, CA) equipped with a 50-kg compression load cell and a Warner–Bratzler V-notch blade to determine Warner–Bratzler shear force values. The cross-head speed was 200 mm/min. Warner–Bratzler shear force was reported as the average force required to shear the six cores from each steak.

2.4. Simulated retail display

On the 14th d postmortem, steaks designated for retail display were placed on styrofoam trays and wrapped with oxygen permeable polyvinylchloride film (Stretchable meat film 55003815; Prime Source, St. Louis, MO; Oxygen transmission rate = 1.4 mL/cm^2/24 h at 23 °C). Packaged steaks were displayed in a coffin-type display case. The case was housed in a 2 ± 2 °C cooler to minimize temperature fluctuation. Due to these conditions, the display steaks were not subjected to the temperature flux associated with defrost cycles of typical display cases. Therefore, the display life was likely maximized. Fluorescent lighting (Sylvania F40N, Osram Sylvania, Danvers, MA; Color temperature = 3600 K) was hung approximately 1 m above the case. Light intensity measured at the meat surface was 1200 lx. Steaks were continuously subjected to this lighting during the display period and external light sources were eliminated.

Steaks were evaluated by visual and instrumental measures on day 0, 1, 2, 3, 4, and 5 of simulated retail display. Visual color scores were determined by an eight-member panel trained in accordance with AMSA (1991). Panelists evaluated each steak for overall color, worst point color, and percentage discoloration. For overall color, panelists were asked to evaluate the "average" color of the steaks using an 8-point scale (8 = extremely bright cherry red; 7 = bright cherry red; 6 = moderately bright cherry red; 5 = slightly bright cherry red; 4 = slightly dark red/tannish red; 3 = moderately dark red/tan to brown; 2 = dark red/brown; 1 = extremely dark red/brown). Worst point discoloration was evaluated using the same scale on the point (1.27 cm in diameter) the panelists judged to be the most discolored. Discoloration scores were evaluated using a 7-point scale [7 = total discoloration (100% discolored); 6 = extensive discoloration (80–99%); 5 = moderate discoloration (60–79%); 4 = modest discoloration (40–59%); 3 = small discoloration (20–39%); 2 = slight discoloration (1–19%); 1 = No discoloration (0% discolored)]. Additionally, instrumental color measurements were taken on each day of display using a Hunter Miniscan XE colorimeter (HunterLabs, Reston, VA; 10° observer, D65 Illuminant). The mean of three CIE L^*, a^* and b^* color space value measurements taken on each steak were used in statistical analysis.

2.5. Statistical analysis

Carcass characteristics, Warner–Bratzler shear force values and cooking traits data were analyzed as a randomized complete block design using the Proc MIXED procedure of SAS (SAS Institute, Cary, NC). Feed and water treatments were applied to animals in a 4 × 2 factorial arrangement. The model tested the effects of the feed and water treatments and their interaction. The random effect (blocking factor) was slaughter group. There were two animals representing each treatment combination within each kill group. Retail display data were analyzed as a randomized complete block with repeated measures. Least squares means were generated for all significant interactions and main effects not involved in higher order interactions and were separated using the PDIFF option, when appropriate. A pre-determined probability of Type I error of 0.05 was used for all judgments of significance.

3. Results and discussion

The feed treatment × water treatment interaction, was not a source of variation in the carcass characteristics, and therefore the least squares main effect means are presented in Tables 2 and 3, respectively. Heifers were selected to be uniform in size so that live weights would be similar across treatments. Therefore, it is no surprise that this trait, as well as carcass weight, did not differ with regard to feed or water treatments. Because dressing percentages were calculated using live and carcass weights, dressing percentage did not differ.

Table 2
Least squares means for carcass traits of heifers fed experimental chlorate treatments in the last feeding or for the last 5 d prior to harvest

Trait	Experimental chlorate feed treatment				RMSE[a]	$P > F$
	None	0.01% BW in last meal	0.01% BW for 5 d	0.05% BW in last meal		
Live weight (kg)	391	391	389	409	35.0	0.88
Carcass weight (kg)	235	239	240	253	22.9	0.17
Dressing percentage	60.2	61.6	61.7	62.0	5.62	0.81
Fat thickness (mm)	13.46	14.54	12.13	14.67	3.55	0.17
LMA[b] (cm^2)	75.20	73.71	71.57	76.37	8.36	0.41
Estimated KPH[c] (%)	1.9	1.7	2.1	1.9	0.68	0.42
Yield grade	2.45	2.62	2.58	2.65	0.63	0.82
Skeletal maturity[d]	204	201	198	191	62.5	0.95
Lean maturity[d]	190	180	186	193	15.6	0.15
Overall maturity[d]	206	192	196	194	43.5	0.84
Marbling score[e]	413ab	471b	357a	427ab	105	0.03

Least squares means lacking common letters (a,b) differ ($P < 0.05$).
[a] RMSE = Root mean square error from analysis of variance table.
[b] Longissimus muscle area.
[c] Kidney, pelvic, and heart fat estimated as percentage of hot carcass weight.
[d] Maturity scores 100 = A^{00}; 200 = B^{00}.
[e] Marbling scores 300 = $Slight^{00}$; 400 = $Small^{00}$.

Table 3
Least squares means for carcass traits of heifers given an experimental chlorate treatment in the water for the 12 h lairage before shipping for harvest

Trait	Experimental chlorate water treatment			$P > F$
	No chlorate	Chlorate treated	RMSE[a]	
Live weight (kg)	396	394	35.0	0.88
Carcass weight (kg)	243	241	22.9	0.62
Dressing percentage	61.6	61.2	5.6	0.79
Fat thickness (mm)	14.13	13.27	3.55	0.34
LMA[b] (cm^2)	75.02	73.41	8.36	0.44
Estimated KPH[c] (%)	1.9	1.9	0.6	0.85
Yield grade	2.59	2.56	0.63	0.89
Skeletal maturity[d]	201	196	62.5	0.78
Lean maturity[d]	186	188	15.6	0.58
Overall maturity[d]	198	196	43.5	0.80
Marbling score[e]	412	422	105	0.71

[a] RMSE = Root mean square error from analysis of variance table.
[b] Longissimus muscle area.
[c] Kidney, pelvic, and heart fat estimated as percentage of hot carcass weight.
[d] Maturity scores 100 = A^{00}; 200 = B^{00}.
[e] Marbling scores 300 = $Slight^{00}$; 400 = $Small^{00}$.

Adjusted fat thickness, longissimus muscle area, estimated percentage kidney, pelvic, and heart fat, and USDA yield grade did not differ across treatments. Because the treatments investigated in this study were applied during the last 5 d of feeding, in the last feeding, or during the time between feed withdrawal and harvest, they would not be expected to affect carcass fatness or muscling traits. These heifers were small framed and therefore produced carcasses that are much lighter than the average produced by the US beef population (McKenna et al., 2002). However, the least squares means for adjusted fat thickness indicate that these animals were adequately finished and harvested at an appropriate point in their growth curve.

Carcass maturity did not differ due to experimental chlorate treatments, and the carcasses averaged in the youngest maturity category ("A" maturity). However, several of these carcasses displayed considerable ossification in the thoracic buttons and throughout the vertebral column. The range in skeletal maturity scores was from A^{50} to D^{10}. The resulting least squares means for skeletal maturity were at the upper limit for A maturity or lower limit for B maturity. Cattle of Mexican origin are known to be variable in regard to skeletal maturity (Hale, Tipton, Paschal, Bretz, & Savell, 1995). In a comparison of dentition and USDA maturity scores, Lawrence, Whatley, Montgomery, and Perino (2001) found that steers of Mexican origin with 0 or 1 pair of permanent incisors had a higher percentage of carcasses with B or C maturity than a random selection of US carcasses from the same dentition categories.

Differences in marbling score were found between experimental chlorate feed treatments. Cattle fed the chlorate product at 0.01% of their body weight for 5 d before harvest had lower marbling scores compared to those fed the chlorate product at 0.01% of their body weight in the last feeding. Neither of these groups had marbling scores different from the non-supplemented controls. Once again, the animals used in this study were variable and the sample size ($n = 16$ per feed treatment) was relatively small. Therefore, we attribute the observed differences in marbling scores to pre-existing variation in these cattle.

The water and feed treatments did not affect cooking losses or cooking times of steaks (Table 4). Feed treatment interacted with water treatment to impact Warner–Bratzler shear force values (Table 5). The water treatment did not affect tenderness in animals

Table 4
Least squares means for cooking traits of heifers given an experimental chlorate preparation in the feed in the last feeding or during last 5 d of feeding and water during 12 h lairage prior to harvest

Treatment	Cook loss (%)	Cook time (min)
Experimental chlorate feed treatment main effect		
	0.21[a]	0.68[a]
Control	32.80	32.17
0.01% BW in last feeding	30.19	31.18
0.01% BW last 5 d	31.83	32.52
0.05% BW in last feeding	33.11	33.26
Experimental chlorate water treatment main effect		
	0.91[a]	0.61[a]
No chlorate	32.04	32.60
Chlorate treated	31.93	31.97
RMSE[b]	4.19	4.84

[a] $P > F$.
[b] RMSE = Root mean square error from analysis of variance table.

Table 5
Least squares interaction means for Warner–Bratzler shear force (*N*) values for heifers given experimental chlorate preparations during 5 d of feeding or in the last feeding or in water during 12 h of lairage after feed withdrawal before harvest

Feed treatment	Water treatment	
	No chlorate	Chlorate treated
	0.02[a]	
Control	41.87b	39.97ab
0.01% BW in last feeding	46.67bc	47.63bc
0.01% BW in last 5 d	51.54c	40.36bc
0.05% BW in last feeding	39.24a	57.99c
RMSE[b]	12.93	

Least squares means lacking common letters (a–c) differ ($P < 0.05$).
[a] $P > F$.
[b]RMSE = Root mean square error from analysis of variance table.

that received either the control diet or the chlorate product at 0.01% of their body weight in the last feeding. However, the animals receiving the chlorate product at 0.01% of their body weight for 5 d before harvest had higher Warner–Bratzler shear force values when not given the water treatment. The large mean for this group is largely due to one individual with an exceptionally high shear force value (100.45 N). Animals that were treated with the chlorate product at 0.05% of their body weight in their last feeding, but not given chlorate in the water produced steaks that were more tender than all groups other than the animals given chlorate in the water, but no chlorate product in the feed. However, the 0.05% of body weight feed treatment, when given in conjunction with water treatment produced steaks that were tougher than all other groups except those given 0.01% of their body weight as the chlorate product in the last feeding, but with no water treatment. Though the differences in tenderness were large, they did not follow any distinct pattern in regard to the application of experimental chlorate preparations in the feed or water. The fact that the feed and water treatment main effects were not significant might suggest that the water × feed treatment interaction is due to pre-existing variation and not caused by the treatments themselves. Therefore, even though large differences were observed in the mean shear force values, sufficient evidence does not exist to conclude that these treatments have an effect on tenderness.

The least squares means for the visual and instrumental color scores from simulated retail display are presented in Table 6. Panelists were asked to assign overall color scores by evaluating the "average" color of the entire steak and the worst point color scores by evaluating an area at least 1.27 cm in diameter which they felt was not represented by the overall color score. Additionally, the panelists estimated the percentage of the steak that had been discolored on each day of display. Analysis of variance indicated that neither water nor feed treatment interacted with display time to impact any of these measures of muscle color. Throughout display, feed treatment had no effect on any subjective or objective color measurement. Furthermore, water treatment did not affect the color measurements. These findings indicate that sodium chlorate has no effect on muscle color regardless of the mechanism for delivery.

The overall color scores declined incrementally during the 5 d of display. This incremental degradation of color was mirrored in the worst point color score and in the increase in surface discoloration. These differences are consistent with meat color degradation. These findings indicate that the steaks in this study responded to simulated retail display in a normal fashion, and that supplemental chlorate fed to the cattle had no effect on the display properties of the steaks.

The changes in color scores are slightly smaller than might be typically observed in a more practical setting. This is most likely due to the temperature used for the display environment. The display temperature used in this study was lower than that typically used for retail display. With our equipment, this temperature allowed greater control of display conditions than at the slightly warmer temperatures commonly used by other investigators. It is likely that the reduced temperature slowed the chemical reactions responsible for color changes.

The instrumental color measurements were consistent with the subjective color scores throughout display. Neither L^*, a^*, or b^* values were altered by supplemental chlorate applied in either the feed or water. Furthermore, values for L^* did not change during the display period. Redness (a^*) values of the steaks gradually declined during the display period. The loss of red color is consistent with discoloration. Finally, the yellowness (b^*) values decreased with display time. These changes are also consistent with natural discoloration of beef. The observed changes during retail display are consistent with the reports of other investigators (Hunt et al., 2003; Yancey, Hunt, Dikeman, Addis, & Katasnidis, 2001).

Table 6
Least squares for subjective and objective color values for steaks from animals treated with experimental chlorate in feed during the last 5 d of feeding or in the last feeding and in water during 12 h of lairage following feed withdrawal before harvest during 5 d simulated retail display

Treatment	Overall[a]	Worst Point[a]	Discolor[b]	L^*	a^*	b^*
Experimental chlorate feed treatment main effect						
	0.61[c]	0.34[c]	0.51[c]	0.17[c]	0.90[c]	0.83[c]
Control	5.15	4.62	1.64	37.62	22.83	17.99
0.01% BW last feeding	4.85	4.31	1.77	35.94	21.99	17.65
0.01% BW last 5 d	4.97	4.51	1.67	37.00	22.25	17.78
0.05% BW last feeding	4.84	4.11	1.90	35.80	22.44	17.34
Experimental chlorate water treatment main effect						
	0.32[c]	0.49[c]	0.93[c]	0.85[c]	0.50[c]	0.94[c]
No chlorate	5.04	4.46	1.75	36.50	22.64	17.71
Chlorate treated	4.86	4.32	1.74	36.67	22.11	17.67
Day of display main effect						
	<0.001[c]	<0.001[c]	<0.001[c]	0.50[c]	<0.001[c]	<0.001[c]
0	5.61f	5.42f	1.09a	36.71	24.89f	19.10f
1	5.30e	5.12e	1.17a	36.49	24.12e	18.51e
2	5.05d	4.60d	1.55b	36.54	22.90d	18.05d
3	4.89c	4.34c	1.73c	36.90	22.47c	17.69c
4	4.66b	3.81b	2.10e	36.40	20.96b	16.87b
5	4.19a	3.04a	2.83e	36.47	18.91a	15.92a
RMSE[d]	0.75	0.94	0.68	2.94	3.02	1.94

Least squares means within day of display main effect lacking common letters (a–f) differ ($P < 0.05$).
[a] 8 = Extremely bright cherry red; 1 = extremely dark red/brown.
[b] 8 = Total discoloration; 1 = no discoloration.
[c] $P > F$.
[d] RMSE = Root mean square error from analysis of variance table.

Collectively these findings indicate that supplemental chlorate given to cattle has no effect on the display properties of beef regardless of the method of administration.

4. Conclusions

Chlorate ion supplementation before slaughter is a promising intervention strategy for reducing the incidence of pathogens on beef carcasses. In our study, the experimental chlorate supplementation did not substantially affect carcass grade characteristics. Furthermore, steaks from chlorate treated animals did not differ from controls during simulated retail display. Although tenderness differences existed, it is not clear whether or not they were caused by the feed or water treatments or by variation existing before to the initiation of the study. Further research is needed on a larger number of animals to further clarify the effects of supplemental chlorate preparations on carcass and meat quality.

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